

Space-division optical switches based on semiconductor optical amplifiers

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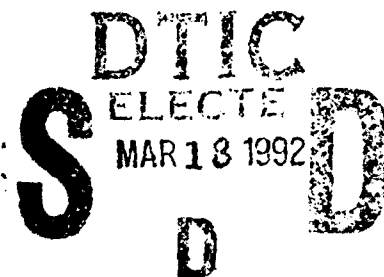
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Abstract

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Benes and *distributed* gain matrix-vector multiplier (MVM) switches larger than $10^{10} \times 10^{10}$ can, in principle, be achieved by using semiconductor optical amplifiers (SOAs). In contrast, *lumped* gain SOA-based MVM switches are limited in size to less than 100×100 .



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Size limitations of space-division switching fabrics based on semiconductor optical amplifiers

Introduction - Traditional networks using time-division multiplexing are limited in throughput by the electronics at their nodes. All-optical space-division switches avoid this bottleneck. Semiconductor optical amplifiers (SOAs) can be used in optical switches to provide both gain and fast switching (< 10 ns). We consider three SOA-based switching architectures, each of which is capable of connecting N input nodes to N output nodes (referred to here as a switch of size N).

Architectures - In the Benes switch (Fig. 1a), 2×2 switches arranged in $2 \log_2 N - 1$ switching "planes" provide a rearrangeably nonblocking interconnection [1]. Total splitting and combining losses of $2/N^2$, as well as excess losses, are compensated by the gain of the SOAs. In the lumped gain matrix-vector multiplier (MVM) crossbar switch (Fig. 1b), two SOAs are encountered along any path through the switch; the first SOA compensates for the $1/N$ splitting loss while the second compensates for the $1/N$ combining loss. In the distributed gain MVM crossbar of Fig. 1c, SOAs are placed after each 1×2 splitter and 2×1 combiner to compensate for losses, with any path through the switch encountering $2 \log_2 N$ SOAs.

Analysis - A path through a SOA-based switch is essentially a cascade of SOAs between which there are splitting, combining, and excess losses (including those incurred in coupling to the SOAs). Our system model assumes that all SOAs are adjusted to provide equal gain.

In optically amplified systems, the post-detection SNR is typically dominated by terms related to the spontaneous emission, which grows as more SOAs are encountered. We assume that, due to saturation effects, the system size limit is reached when the accumulated spontaneous emission plus signal exceeds some maximum output power P_{max} . We operate under the constraint that the signal level must be adequate to provide the required SNR, and further assume that the gain exactly compensates the loss through the system so that the signal experiences a net gain of unity.

Results - Fig. 2 shows how the maximum system size varies with P_{max} for the three architectures. For the lumped gain MVM switch, the achievable switch size is limited to $N < 100$. However, for both the Benes and distributed gain MVM switches, the switch size

increases exponentially with P_{max} , reaching $N > 10^{10}$ for the modest values $P_{max} = 1$ mW and 30 nm optical filtering. This is due to the fact that the spontaneous emission grows only logarithmically with switch size. The use of multiple optical filters placed within the switching fabric reduces saturation by spontaneous emission and improves post-detection SNR.

Conclusions - Based on saturation and noise considerations related to spontaneous emission, Benes and distributed gain MVM crossbar switches utilizing SOAs can, in principle, achieve sizes of $N > 10^{10}$. In contrast, lumped gain MVM crossbar switches are limited to sizes of $N < 100$. This illustrates the general advantage of compensating small losses with small gain amplifiers instead of compensating large losses with large gain amplifiers.

In our presentation, we will also consider the impact of additional phenomena in SOA-based switches including crosstalk due to the non-zero transmission of SOAs in the off-state, intersymbol interference at high signal levels due to saturation [2], and variations in excess losses.

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- [2] A. A. M. Saleh and I. M. I. Habbab, "Effects of Semiconductor-Optical-Amplifier Nonlinearity on the Performance of High-Speed Intensity-Modulation Lightwave Systems," *IEEE Trans. Commun.*, vol. 38, no. 6, pp. 839-846, 1990.
- [3] C. H. Henry, "Theory of Spontaneous Emission Noise in Open Resonators and its Application to Lasers and Optical Amplifiers," *J. Lightwave Technol.*, vol. 4, no. 3, pp. 288-297, 1986.

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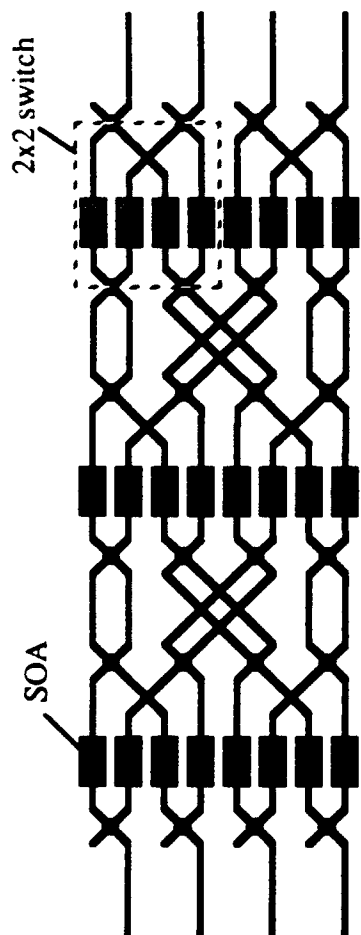
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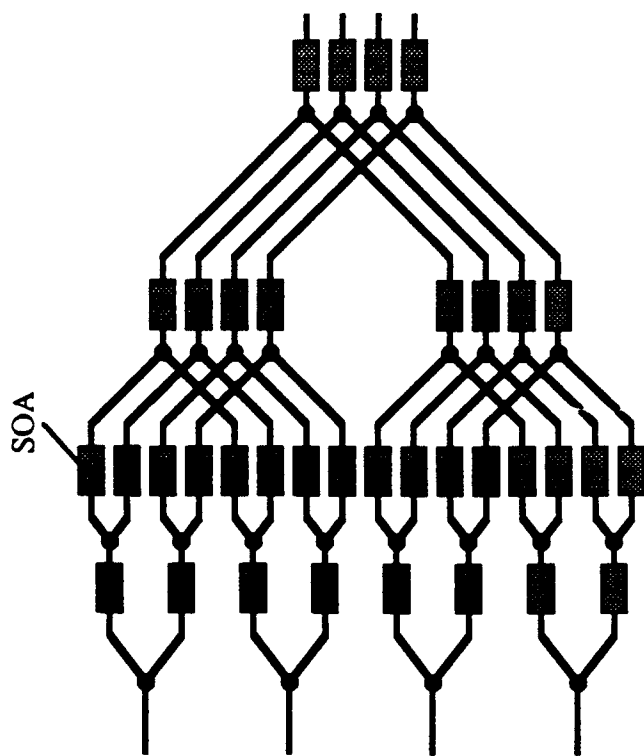
Figure Captions

1. (a) 4x4 Benes switch; (b) 4x4 lumped gain matrix-vector multiplier (MVM) switch; (c) 4x4 distributed gain MVM crossbar switch.

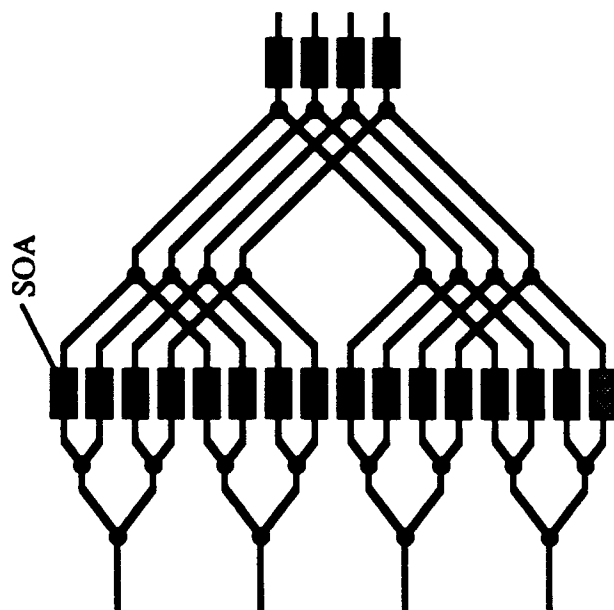
2. Maximum switch size vs. maximum SOA output power. The system parameters are: bit rate is 1.5 Gb/s, receiver noise bandwidth is 1 GHz, excess losses incurred in coupling into or out of each SOA is 3 dB, and $n_{sp} = 2$ (excess spontaneous emission factor [3]).



(a)



(c)



(b)

